
Chapter 7

Concrete Main Components

CONCRETE MAIN COMPONENTS

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Raw Materials and Product Technology

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1. MAIN COMPONENTS OF CONCRETE

1.1 Definition of concrete

Concrete is a composite material
**that consists of aggregate (gravel + sand),
cement and water
and frequently admixtures and/ or additives.**

The aggregate consists of a conglomerate of generally different large grains, mostly natural rocks. In particular cases also of waste wood, polystyrene or metals (waste steel or other).

As binders hydraulic materials are used, generally ordinary Portland cement. In special cases asphaltic materials or artificial resin will be applied.

Aggregates are generally designated as either fine (sand: 0.025 to app. 5 mm) or coarse (gravel: from app. 5 to 32 mm or larger). A 'concrete' with sand only is named mortar.

The cement paste coats the particles of aggregate and fills the spaces between them. While fresh, the cement paste also provides the lubrication that reduces the friction between the aggregate particles and imparts workability to the fresh mix. When hardened, the paste (now called cement stone) binds together the particles of aggregate.

The following figure shows the

SYSTEM: Binder + Water + Aggregate = Concrete

General Case				
Concrete	=	Filler	+	Binder
Special Case				
OPC concrete	=	(Gravel + Sand) aggregate	+	OPC paste
Mortar	=	Sand	+	OPC paste
OPC paste	=	OPC	+	Water

1.2 Cement

The most important component of concrete, the cement, has been treated in detail in a separate chapter.

1.3 Aggregates

1.3.1 Aggregates from natural sources

Definition

Natural aggregates are a mixture of uncrushed and/or crushed rocks and minerals. It consists of particles of different (or sometimes approx. equal) sizes and are used with a binder (cement) and water to produce concrete or mortar [1].

General

The mineralogical, physical and chemical characteristics of rocks are determined mainly by the events of their geological history. A knowledge of the ways in which rocks are formed, and of the various natural processes (whereby their original characteristics are altered) may therefore lead to a better understanding of those intrinsic properties which determine the suitability of a rock as a source of concrete aggregate.

Rock classification according to their formation:

- ◆ Igneous rocks
- ◆ Sedimentary rocks
- ◆ Metamorphic rocks

Igneous rocks

Igneous rocks are those which are formed by the solidification of molten masses, and many of their characteristics are determined by the rate and condition of cooling. Extruded volcanic rocks, i.e. those which have been ejected on the earth's surface, are cooled very rapidly, so that crystallisation of the component minerals is generally only partly effected, and the resulting rock consists of a mixture of crystalline ingredients and glassy matter.

On the other hand rocks of the intruded igneous type, i.e. those which are formed from molten rock which has been intruded into overlying rock masses to form sills (a tabular intrusion of the surrounding rock), laccoliths (a concordant intrusion that has domed the overlying rocks) and dikes (rock solidification as a tabular body in a vertical fissure) etc. have been allowed to cool slowly, so that all the several compounds of the rock mass have had time to become thoroughly crystallised [8, 9].

The igneous rocks are the primary rocks and from these all the other rocks are ultimately derived. The mineral constituents of igneous rocks have been classified as follows:

Table 1: Minerals of igneous rocks

Feldspathic silicates	Free silica
Orthoclase	Quartz
Plagioclase	Tridymite
Leucite	Opal
Ferromagnesian silicates	Accessory minerals
Pyroxene	Magnetite
Amphibole	Ilmenite
Biotite	Haematite
Olivine	Apatite

Sedimentary rocks

Sedimentary rocks are derived from the chemical or mechanical breakdown of older rocks. The fragments resulting from such disintegration accumulate in deposits, for the most part under water, and the particles may be cemented together by the deposition of other siliceous, calcareous, argillaceous or ferruginous materials to form a dense mass.

Chemical precipitates are crystalline, but by far the greater proportion of sedimentary rocks are made up of fragments of all sizes of earlier rocks. As in the case of sand or gravel beds, the fragments may lie loosely together, or may be firmly cemented as a compact material.

The fragments of the older rocks may be sharply angular, but as they are often transported by wind or by water or by glacier for considerable distances, attrition may cause them to become smoothly rounded in their passage to the final deposit.

As a result of their mode of deposition, the structure of sedimentary rocks is almost invariably stratified, and is essentially different from that of igneous rocks. Glacial deposits or coral reefs are not stratified and in this respect differs from other rocks of this class.

Due to the geological and climatological changes, sudden radical changes often occur in the nature of the material being deposited. For this reason limestone are frequently interbedded with shale, sandstone with siltstones and quartzite with dolomite [3].

Metamorphic rocks

Metamorphic rocks are those resulting from the alteration in place of pre-existing sedimentary or igneous rocks. Such alteration is brought about by the application of high temperatures and/ or pressures to the rock mass.

A large group of rocks in this class is characterised by foliated structure, which is not to be confused with the stratification of sedimentary rocks nor with the flow banding of some lava, but which is the result of the segregation of one or more of the constituents minerals and their reorientation in form of parallel plates.

Metamorphic rocks vary greatly both in structure (the attitude and relative position of the rock masses of an area) and in texture (the general appearance of a rock, e.g. the size, shape, and arrangement of the constituent elements). Where the rock has been formed under high temperature and pressure, an equigranular texture and a massive internal structure results and lend great strength and toughness to the rock. Such rocks include many hornfelses and quartzites.

1.3.2 Classification

From the petrologic view of point the aggregates, whether crushed or naturally reduced in size, can be divided into several groups of rocks having common characteristics. The group classification does not imply suitability of any aggregate for concrete-making: unsuitable material can be found in any group, although some groups tend to have a better record than others.

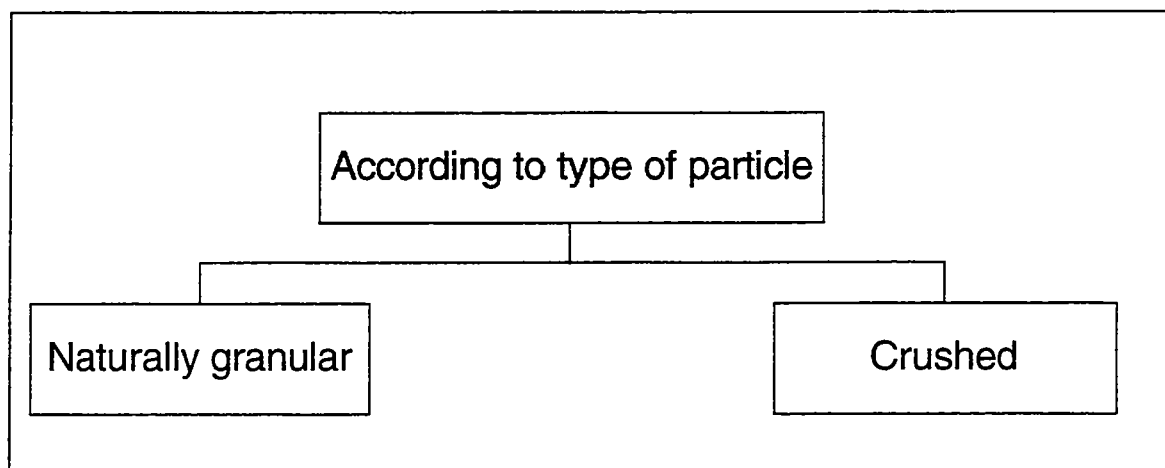
Table 2: Classification of natural aggregates according to rock type [4].

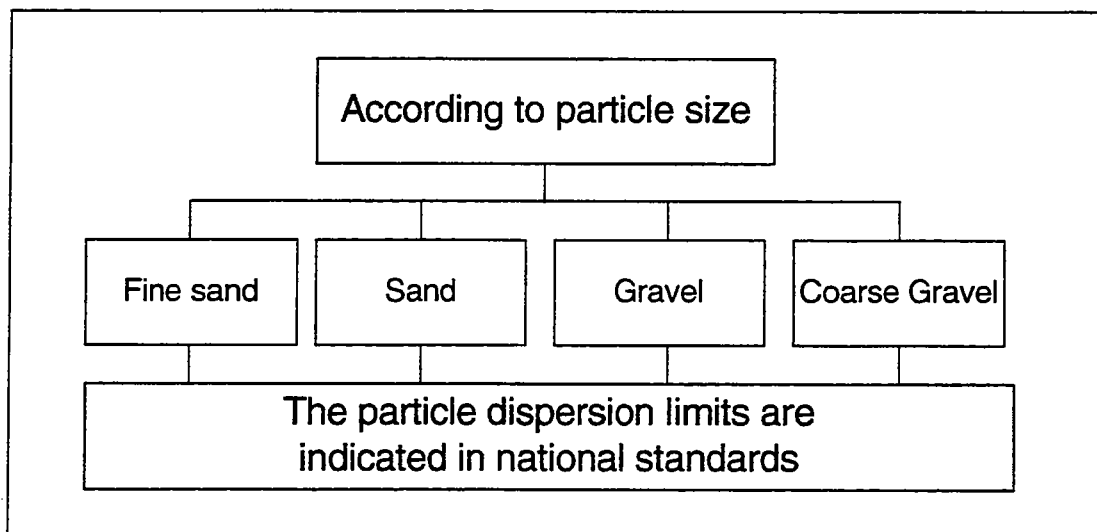
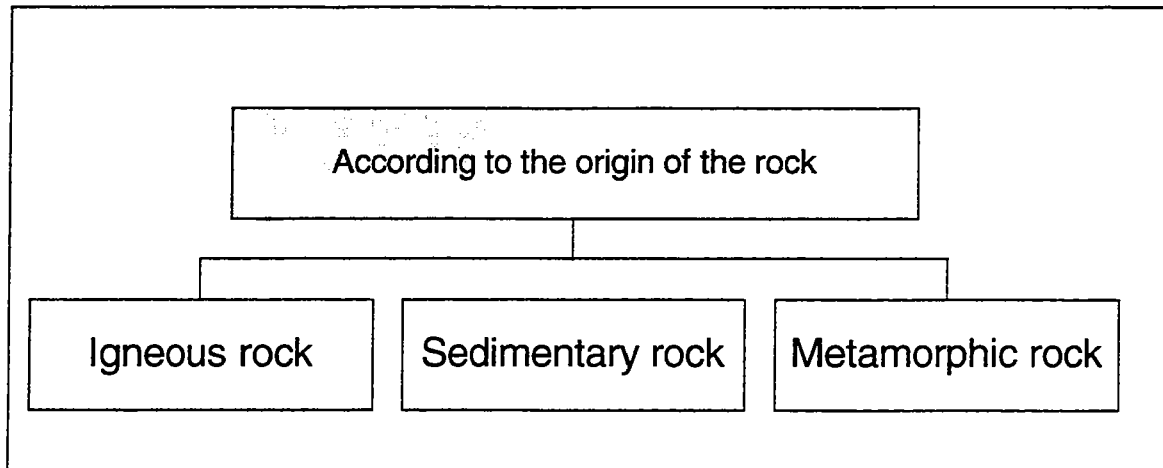
Basalt Group	Flint Group	Gabbro Group
Andesite Basalt Basic Porphyrites Dolerites Spillite	Chert Flint Hornstone	Basic Diorite Basic Gneiss Gabbro Hornblende-rock Norite Serpentine
Granite group	Gritstone group	Hornfels group
Gneiss Granite Granulite Pegmatite Syenite	Arkose Greywacke Grit Sandstone Tuff	Contact-altered rocks (all kinds except marble)

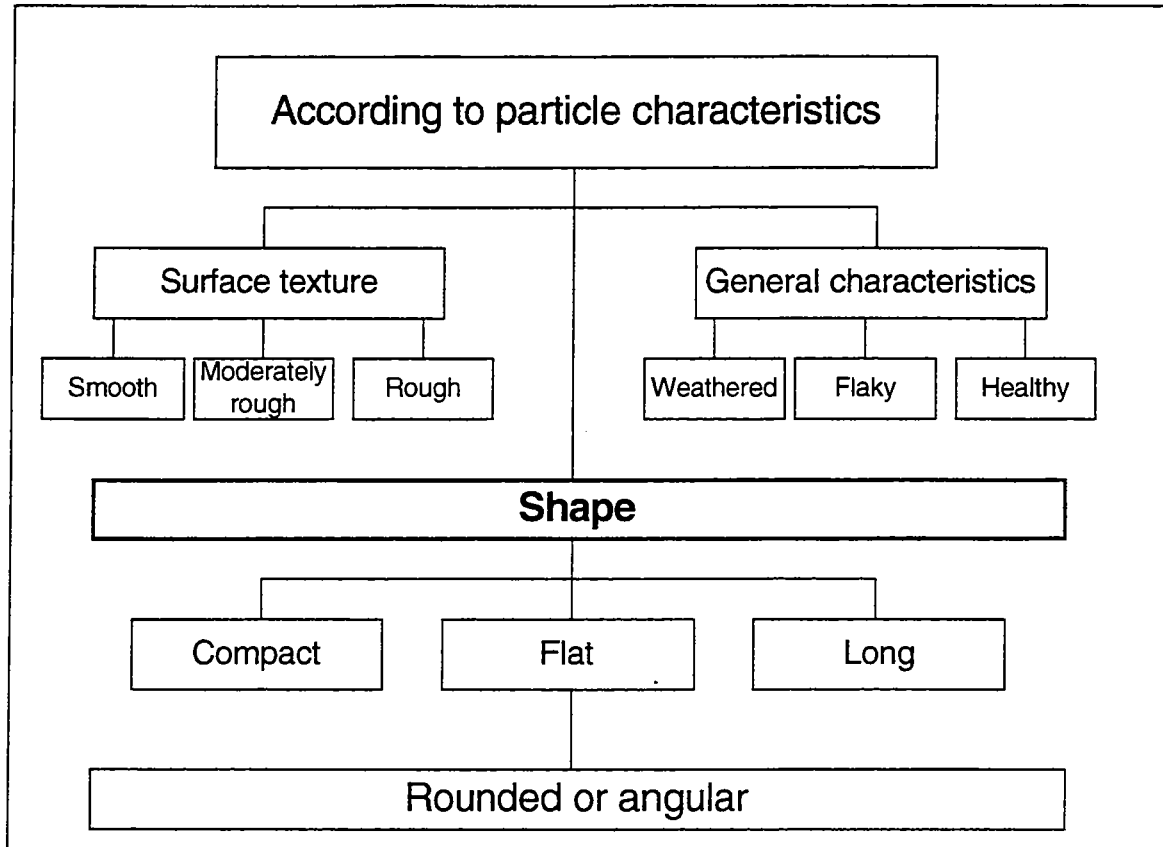
Pophyry Group	Limestone group	Quartzite group
Aplite Felsite Granophyre Porphyry Rhyolite Trachyte	Dolomite Limestone Marble	Ganister Quartzitic sandstone Re-crystallized quartzite

Schist group
Phyllite Schist Slate All severely shared rocks

Figure 1: Classification according other parameters:







1.3.3 Chemical properties

While it is desirable that the aggregate should as far as possible be chemically inert, many natural aggregates contain substances which are deleterious in concrete. Substances considered chemically deleterious may be broadly classified into five groups:

Group 1:

Substances **soluble in water**, which may be leached out of the aggregate thereby weakening it or promoting efflorescence in the concrete, e.g. common salt.

Group 2:

Soluble substances, or substances which become **soluble in the cement matrix**, which may interfere with the normal hydration of the cement, e.g. humid acid.

Group 3:

Substances which **react with the cement** destroying its properties, e.g. sodium sulphate.

Group 4:

Substances which may **react with the alkali** constituents of the cement, e.g. opal (AAR, Alkali-Aggregate Reaction).

Group 5:

Substances which may **cause corrosion** of reinforcing steel, e.g. common salt.

1.3.4 Physical properties

Perhaps the most important concept developed from research is that the aggregate must be studied not only in its relation to the hardened cement paste, i.e. as a component of concrete, but in relation to the environment of the concrete during its service life. With this

concept in mind, the physical properties of natural stone aggregates may be considered in terms of following factors:

Table 3: Properties of rocks

Rock Type	Various properties			Strength Properties			
	Relative density [kg/m ³]	Water Absorption [Vol. %]	Compression str. [MPa]	10%-Crushing value [kN]	Modulus of rupture [MPa]	Modulus of elasticity [GPa]	Shear strength [MPa]
Andesite	2,7 - 2,9	0,4 - 0,5	500 - 540	450	--	80 - 110	--
Basalt	2,8 - 3,0	0,1 - 0,3	190 - 470	340	14 - 24	49 - 98	--
Dolerite	2,8 - 3,1	0,1 - 0,7	160 - 375	180 - 340	14 - 24	60 - 105	--
Dolomite	2,7 - 2,9	0,1 - 0,3	200 - 380	130 - 180	--	100 - 130	--
Felsite	--	0,2 - 1,5	360 - 450	230 - 380	--	70 - 90	--
Granite	2,6 - 2,8	0,2 - ,5	70 - 325	120 - 220	0 - 20	14 - 70	14 - 30
Hornfels	2,6 - 2,8	--	--	140 - 260	--	--	--
Limestone	2,6 - 2,9	0,2 - 0,6	20 - 240	180	4 - 15	21 - 71	8 - 21
Marble	2,6 - 2,9	0,2 - 0,6	20 - 240	--	4 - 24	48 - 96	9 - 45
Quartzite	2,6 - 2,8	0,2 - 0,6	105 - 480	160 - 280	12 - 24	64 - 86	--
Rhyolite	2,6 - 2,8	--	180 - 530	210 - 290	--	--	--
Sandstone	2,5 - 2,7	0,2 - 0,9	10 - 255	50 - 280	3 - 14	14 - 55	2 - 21
Syenite	2,6 - 2,7	0,4 - 1,5	95 - 445	--	--	55 - 72	--

Strength

The compressive strength of cubical specimens of natural stone from which acceptable aggregate is derived, normally varies from about 70 to 400 MPa, while individual results as high as 540 MPa have been recorded [5].

With a wide range there appears to be only a poor correlation between the compressive strength of the aggregate and the flexural or compressive strength of the concrete.

As an index of overall quality the "10 % fines aggregate crushing value" or 10 % FACT value of coarse aggregates is useful (BS 812). However, it must be repeated that the usefulness of these tests is confined to a general assessment of quality and to the establishment of acceptance limits. New researches by Davis and Alexander have, however, shown a relationship between the aggregate type and the properties of concrete [6].

Elasticity

The modulus of Elasticity of concrete depends to a considerable degree on that of the aggregate from which it is made. The flexural strength of concrete is also depending on this property of the aggregate, and the use of an aggregate having a high elastic modulus will usually result in a concrete of high flexural strength, other factors being equal [7].

The drying shrinkage of concrete is reduced by the use of aggregate having a high elastic modulus. Low shrinkage, induced by the use of rigid aggregates may be undesirable as the restraint provided by the aggregate increases the cracking tendency of the paste, thereby reducing the durability of the concrete.

It would appear on balance that the reduction in durability resulting from the use of aggregate of high elastic modulus would in most cases more than offset any advantages which may be gained thereby.

Porosity

Many authorities consider that the size, abundance and continuity of pores in a rock particle are its most important physical properties. It is considered that the size and nature of the pores affect the physical strength of the aggregate, and control water absorption and permeability, thereby determining the durability of the aggregate in regard to freezing and thawing, and its resistance to chemical attack.

It has been previously pointed out that the strength of the aggregate over a wide range cannot be considered as an important factor. Furthermore, in tropic countries a high resistance of freezing and thawing is not often an important quality of concrete. This property should, however, be considered where impermeability or high resistance of chemical attack are important features of the construction. Sandstone and shale show an average porosity of 18 to 19 %, some limestone types 8 % and quality rocks 1 to 3 %. Individual results may be much higher [3].

Thermal expansion

In recent years it has come to be appreciated that the deterioration of concrete structures may be significantly affected by differences between the coefficients of thermal expansion of aggregate and the cement matrix in which it is embedded. In particular, the use of an aggregate of very low coefficient of expansion may lead to disintegration of the concrete. As the temperature of concrete, made with such an aggregate is lowered, the cement paste tends to contract more than the aggregate, with the result that tensile stresses are set up in the former, which may result in cracking.

Bond characteristics

Perhaps one of the most important attributes of a concrete aggregate is its capacity for bonding strongly with cement paste. This factor has a significant influence on the flexural strength [7].

In a wider field the word "surface texture" should be replaced by "bond characteristics". The latter term embraces not only surface texture, but the extent to which cement paste can penetrate into pores are surface depressions, the angularity of planes of fracture, the friable of the surface, and the presence or absence of loosely bonded or friable coatings.

The effect of bond characteristics, while sufficiently significant in the medium strength range of mixes, becomes much more pronounced in the case of high-strength concretes.

Particle shape and surface texture

The shape of aggregate particles in both sand and stone, is one of the most significant factors affecting the behaviour of a concrete mix. Concrete water demand and water requirement on the design of concrete mixes, are strongly influenced by the shape of aggregate. Spherical, cubical or chunky shapes produce concrete having lower water demand than particles that are elongated or flaky.

Surface texture of the grains also affects water demand, although to a lesser extent than shape. Rough textures increase water demand due to greater surface area and to increase friction and mechanical interlock of the particles.

It seems that the shape and surface texture of aggregate influence considerably the strength of concrete. The flexural strength is more affected than the compressive strength. Some data of Kaplan's research [7] are reproduced in the following table, but this gives more than an indication of the type of influence.

Table 4: Effect of aggregate properties

Property of concrete	Relative effect of aggregate properties		
	Shape	Surface Texture	Modulus of Elasticity
Flexural strength	31 %	26 %	43 %
Compressive strength	22 %	44 %	34 %

Thermal properties

Thermal properties which may be of significance are:

- specific heat (or heat capacity)
- thermal conductivity
- thermal diffusivity

All these properties are significant in the design of radiation shielding for nuclear power plants and in estimating loads on air-conditioning plant for buildings.

Resistance to abrasion

This is of significance in the choice of aggregate for pavements, industrial floors, channels, conveying abrasive materials and for certain type of silos.

Soundness

The sulphate soundness test (ASTM, C 88 and SABS 1083) is not highly significant but provides a rough indication of the durability of an aggregate when subjected to expected environmental conditions. There is no evidence available to suggest that the mechanism of disruption of the test can be directly correlated with performance of an aggregate when subjected to these conditions. For this reason it is important that when an aggregate is to be evaluated on the basis of this test, it should be done by comparison with an aggregate of similar mineralogical composition and geological history and which has proved to be satisfactory in practice.

1.3.5 The grading

The grading of an aggregate refers to the distribution of particles of various sizes, and is determined by passing a representative sample through a series of standard sieves. Concrete aggregates are divided into two categories of fine aggregate or sand and coarse aggregate or stone. The boundary between these two is the 4 mm sieve but a fine aggregate may contain a small proportion of oversized particles and coarse aggregates may have some undersized material and still comply with the definition.

The German standard DIN 1045 sieves for fine and coarse aggregates are:

0.25 - 0.50 - 1.0 - 2.0 - 4.0
8.0 - 16.0 - 31.5 - 63.0 - mm

The sizes of the openings in the consecutive sieves are related by a constant ratio, the clear opening of each sieve size being twice or nearly twice that of the next smaller size.

Fineness modulus

The grading analysis provides data from which the fineness or coarseness of aggregate can be judged. The measure of fineness or coarseness is expressed in terms of an index known as the fineness modulus or FM. This is defined as an empirical factor obtained by adding the total percentages of material retained on each of the standard sieve sizes, except this amount smaller than 0,25 mm, and dividing the sum by 100. An example is given in the following table:

Table 5: Determination of fineness modulus

Sieve size [mm]	Mass retained on sieve [g]	Mass retained on sieve [wt-%]	Total retained on sieve [wt-%]*	Total passing on sieve [wt-%]
31,5	<1,0	0,0	0,0	100,0
16,0	1980,0	38,0	38,0	62,0
8,0	1250,9	24,0	62,0	38,0
4,0	781,9	15,0	77,0	23,0
2,0	469,1	9,0	86,0	14,0
1,0	312,7	6,0	92,0	8,0
0,5	156,4	3,0	95,0	5,0
0,25	156,4	3,0	98,0	2,0
< 0,25	104,2	2,0	(100,0)	0,0
Total	5212,0	100,0	548,0	---
Fineness Modulus FM		5,48		

The FM is an index of the material, that is, a measure of the average particle size based on purely empirical classification. But the index in itself does not describe the grading. The FM indicates whether a material is fine, medium or coarse. A very fine aggregate grading with a maximum grain size of 31,5 mm is one having a modulus of 3,30 or less but in general run up to about 4.0. Medium aggregates are those with FM from 4.0 to 5.0 while coarse aggregates have higher fineness modulus (> 5.5).

Grading of sand

While the grading of a sand has a relatively minor effect on water demand, it has a major influence on the workability, cohesiveness and bleeding properties of concrete in its plastic state. Experience gained over many years has shown that the proportions of sand passing the 0.090, 0.125 and 0.25-mm sieves have the greatest effect on the properties of the mix while the contribution on the remaining fractions is less significant. Real values are shown in the following table:

Table 6: A guide to sand grading

Sieve Size [mm]	Percentage passing	
	Suggested outer limits	Preferred limits *)
4,0	80 - 100	90 - 100
2,8	68 - 100	80 - 100
2,0	55 - 100	75 - 95
1,4	43 - 92	70 - 85
1,0	32 - 85	55 - 70
0,5	16 - 65	40 - 60
0,25	5 - 43	20 - 40
0,125	2 - 22	10 - 20
0,09	0 - 11	3 - 6

*) limits are suggested for pump concrete and for concrete used in sliding formwork

The dramatic increase in surface area as the particle size decrease is illustrated by a few examples. The effect of grading on concrete behaviour is not constant but depends on the cement content and workability of the mix. Generally it may be accepted that a lower cement content calls for a finer grading of the aggregates: in other words, the leaner the mix, the higher should be the proportion of fineness (the total sum of sand $< 0,1$ mm plus cement should be approx. 350 kg per m^3 concrete).

Table 7: Specific surface of various materials

MATERIAL	Specific Surface [m^2/kg]
32-mm concrete aggregate	0,07
Average grading (B32) of aggregates	2,7
Average concrete sand	3,5
Silt	35
Ordinary Portland cement	300
Kaolinite	5'000

Blending of sands

The grading of sand has a more pronounced effect on workability than has that of the coarse aggregate. While sand from a single source may not meet the grading requirements, it is often possible to overcome this difficulty by using a combination of sands.

In the following table the grading is tabulated for the mixture of aggregates of 67 % of the crusher sand and 33 % of the pit sand:

Table 8: Grading of mixture of two sands

Sieve size [mm]	Percent passing		
	Crusher Sand A	Pit Sand B	Mixture 67 % A + 33 % B
4,0	82	100	88
2,0	56	100	71
1,0	45	100	63
0,5	33	97	54
0,25	19	58	32
0,125	7	31	15
0,090	3	18	8
FM	3.58	1.14	2.77

A comparison of concrete with crushed aggregates and concrete with rounded aggregates is shown in the following table:

Table 9: Properties of fresh concrete with crushed aggregates

Fresh concrete
Crushed aggregate has in comparison with rounded aggregate:
<ul style="list-style-type: none"> • Better stability of stiff concrete after immediate demoulding • Comparing flowing properties during vibration • Comparable properties of pumped concrete • Less bleeding • Comparable or better concrete surface • Consistency (on DIN A flow table) less favourable

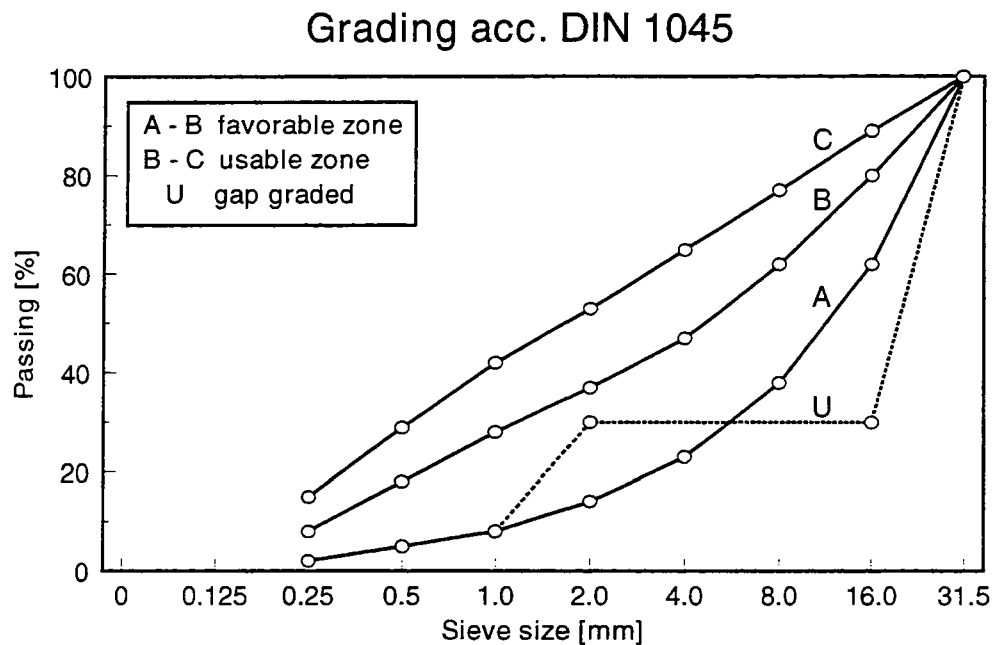
Table 10: Properties of hardened concrete with crushed aggregates

Hardened concrete
Crushed aggregate has in comparison with rounded aggregate:
<ul style="list-style-type: none"> • Better flexural strength • Higher grip resistance • Less depth of water penetration

Grading of stone

The grading of coarse material has a smaller influence on the workability of a mix than that of the sand but haphazard grading cannot be permitted where the quality of the concrete is of importance. For this reason the material is screened into its various size fractions and recombined to conform with specified or suitable grading requirements. The following figure shows the grading limits according to DIN 1045.

Figure 2: Examples of particle size distribution for different gradings



Gap-graded and continuously-graded concrete

The relative merits of concrete made with gap-graded and continuously-graded stone have been much debated [10, 11,12]. The technical advantages of each are listed below but, in comparing merits, it must be stated that economic considerations may outweigh the technical.

Table 11: Properties of gap-graded concrete

Gap-graded concrete [2,12] compared with continuous-graded concrete
<ul style="list-style-type: none"> • Less danger of particle interference. • Greater sensitivity of consistence to change in water content. This makes for more accurate control mixing of water which in turn ensures more consistent strength results. • Stiffer mixes are more responsive to vibration.

Table 12: Properties of continuously-graded concrete

Continuously-graded concrete compared with gap-graded concrete
<ul style="list-style-type: none"> • Wetter mixes are less prone to segregation. • Less sensitive to slight changes in water content. This is an advantage where uniform workability is important. • Improve pumpability especially at higher pressure. • Improve flexural strength due to the increased surface area of graded stone.

1.3.6 Alternative aggregates

Aggregates from natural sources make up the bulk of the aggregates used in concrete. However, there are a number of alternative materials which can be used as aggregate and concrete technologists should be encouraged to explore their potential performance and economy for use in concrete.

Materials used for a greater or lesser extent of natural aggregate are:

◆ **Metallurgical slag**

Metallurgical slags that have been found suitable for use in concrete include blastfurnace, ferromanganese, ferro-silicon-manganite, phosphate, chrome, copper and platinum slag [14].

◆ **Clinker**

Well-burnt furnace residues from furnaces fired with pulverised fuel (BS 1165).

◆ **Expanded Clays** (shale and slate)

When certain clays or shale are rapidly heated to the point of incipient fusion, the material softens, becomes plastic and tends to entrap gases which are generated within its mass. Trade names are: *Haydite, Cel Seal, Aglite, Gravelite, Leca and Güllät*.

◆ **Sintered fly ash**

In one of the manufacturing processes of low-density aggregate from fly ash, the ash is first palletised and then formed noodles are sintered at 1'000 to 1'200 °C.

◆ **Burnt-clay bricks**

Burnt-clay aggregate made by crushing broken bricks is being used more and more to

some extent in cast-in-situ concrete, but mainly for making precast concrete panels and concrete masonry units.

◆ **Colliery Spoil**

In the UK in 1972, two plants were operating on colliery waste and producing an aggregate known as Aglite. It is an expanded low-density aggregate.

◆ **Exfoliated Vermiculite**

Vermiculite is the geological name given for a group of micaceous minerals. It has the unique property that when heated to around 1'200 °C, the flakes expanded (exfoliated) up to 15 times their original volume.

◆ **Perlite**

Perlite and certain other volcanic glasses expand when heated to the point of incipient fusion. Expanded perlite is usually produced only in sand size. It has a maximum bulk density of 240 kg/m³.

◆ **Glass**

Waste glass is a potential aggregate for concrete and has been used in precast concrete elements. Waste glass is susceptible to alkali-aggregate-reaction and may produce concrete with a high expansion if used in combination with a high alkali content.

◆ **Recycled concrete as aggregate**

Depletion of normal aggregate sources and waste disposal problems have made concrete reclaimed from the demolition of concrete structures an attractive proposition as aggregate. Useful data have been published by Buck [13].

◆ **Sawdust and Wood Wool**

Concrete made from mixtures of Portland cement and sawdust is generally a rather unreliable material and its properties cannot be easily predicted.

◆ **Expanded polystyrene**

Expanded polystyrene beads have a closed cellular structure and can easily be used to produce cellular concrete. Expanded polystyrene beads are extremely light (density 12 to 16 kg/m³) so that they can segregate from the mix and are hydrophobic.

◆ **Remarks**

Some of the alternative aggregates, such as air-cooled metallurgical slag are used merely because they are more economical than natural aggregates and can be used without detriment. In other cases, certain technical properties are required (e.g. low density, superior thermal insulation) and for these purposes aggregates are often "purpose-made" for example low-density aggregates such as bloated clay and shale, sintered fly ash and exfoliated vermiculite. Many of these materials are only used to make precast concrete products such as concrete masonry units.

1.4 Admixtures

Admixtures are chemicals which are added in relatively small quantities to the basic constituents of concrete. The quantity of an admixture is usually measured against the quantity of cement, expressed as its percentage by mass.

It is convenient to make a distinction between admixtures and additives. Admixtures are used in quantities of maximum 5 wt-% (usually 0.5 to 2.0%). Additives such as fly ash, or other pozzolanas and blast furnace slag, are applied in quantities of more than 5% by mass of cement (usually 15 to 35%). Additives should therefore be considered as additional constituents of the concrete mix.

Admixtures are usually categorised according to their principal uses or according to their primary effects as follows:

- Improvement of workability of fresh concrete
- Control of setting time and early hardening
- Air-entrainment
- Other effects (stability, high cohesion, colouring, etc.)

The official **definition of an admixture** according to ASTM C125:

- ◆ An admixture is a material other than water, aggregates, hydraulic cement, and fibre reinforcement used as an ingredient of concrete or mortar and added to the batch immediately before or during its mixing.

This definition encompasses a wide range of materials that are utilised in modern concrete technology. Subsections of admixtures are:

- **Accelerating admixtures**
Admixtures that accelerates the setting and early strength development of concrete.
- **Air-entraining admixtures**
Admixtures that causes the development of a system of microscopic air bubbles in concrete or mortar during mixing.
- **Retarding admixtures**
Admixtures that retards the setting of concrete.
- **Water-reducing admixtures**
Admixtures that either increases the slump of freshly mixed mortar or concrete without, increasing the water content, or that maintains the slump with a reduced amount of water due to factors other than air entrainment.

1.4.1 Workability agents

Admixtures in this category are either called

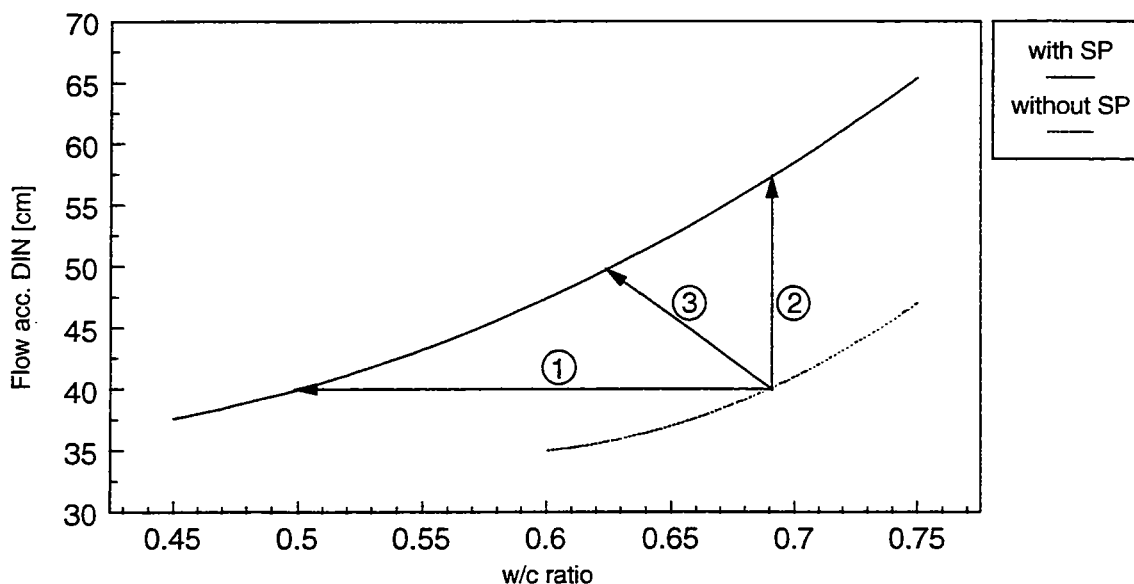
- plasticizers
- superplasticizers
- water-reducing agents
- high range water-reducing agents.

The primary effect of the admixtures is an improvement of workability.

The following diagram shows the different purposes of using plasticizers in a typical concrete mix:

- 1 constant workability (flow); reduced w/c ratio and increased strength
- 2 constant w/c ratio and strength; increased workability (flow)
- 3 mix of both cases

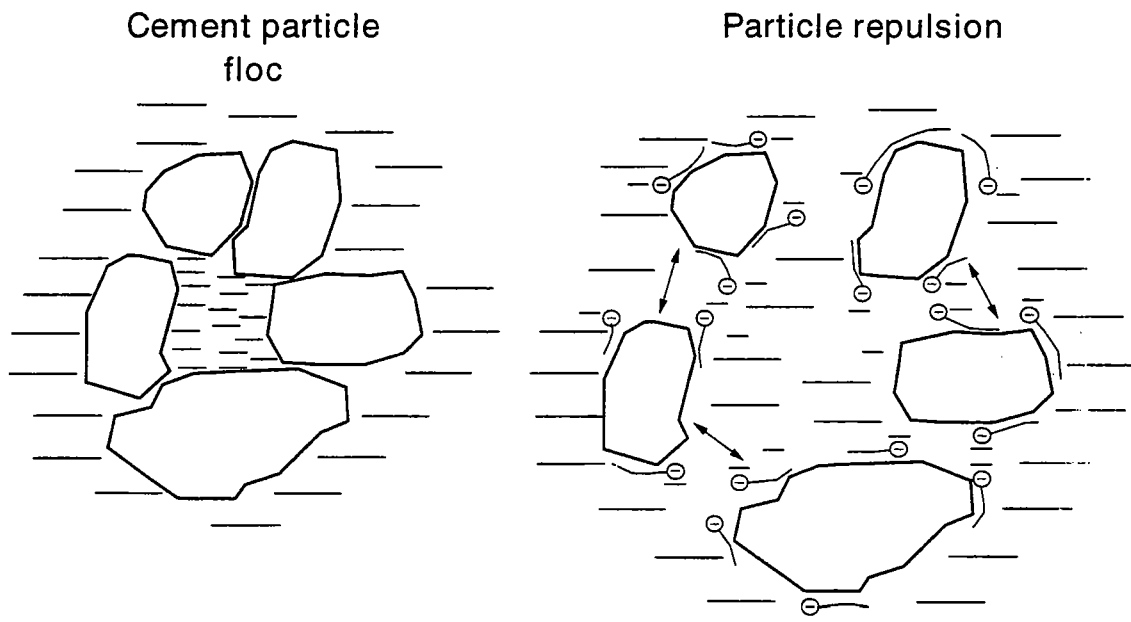
Figure 3:



Admixtures in this group are all based on chemical compounds which affect the forces between solid particles suspended in water and reduces the surface tension of water. The admixtures contain surfactants which is being absorb on the surface of the particles. The strength of the adsorption depends on the type of particle. In case of Portland cement the

C_3A compound appears to provide the strongest attraction. The dispersing action is also enhanced by the development of a layer of adsorbed molecules of the plasticizers which separate the particles of cement; see following figure:

Figure 4:



Flocculated particles of cement before the addition of a superplasticizer

The negative charges of the 'tails' of the molecules of the admixture adsorbed on to the cement particles generate repulsive forces and disperse the particles

The superplasticizers are broadly classified into four groups, namely:

- **SMF:** Sulphonated Melamine-Formaldehyde condensate
- **SNF:** Sulphonated Naphthalene-Formaldehyde condensate
- **MLS:** Modified Ligno Sulphonates
- **Others:** Polyacrylates, sulphonic-acid-esters, carbohydrate esters etc. A very new invention is based on derivatives of maleic acid and vinyl monomers.

Variations exist in each of these classes and some formulations may content a second ingredient.

Ordinary plasticizers

Ordinary plasticizers are mainly based on lignosulphonate salts - a minority use salts of hydroxy-carboxylic acid. Calcium lignosulphonate and the better water soluble sodium lignosulphonate normally used as admixtures for concrete. The lignosulphonate molecules are in the form of polymers with molecular weights varying from approx. 20 to 30'000.

Dosage of lignosulphonate type plasticizers varies between 0.2 to 0.6% of the cement in the mix. The effectiveness of the lignosulphonate plasticizers depends on the composition of the particular Portland cement used. Cements with high content of C_3A are likely to require increase dosage of admixtures. The lignosulphonate admixtures appear to be less effective for cements with moderate high cement content than for mixes with low cement contents, below approx. 270 kg/m^3 .

Lignosulphonate based plasticizers have the tendency to produce significant side effects, namely:

(1) Air-entrainment

The additional percentage of entrained air which can be generated by normal doses varies between 0.5 to 2.5 vol-% (slump approx. 6 cm, cement content approx. 300 kg/m^3).

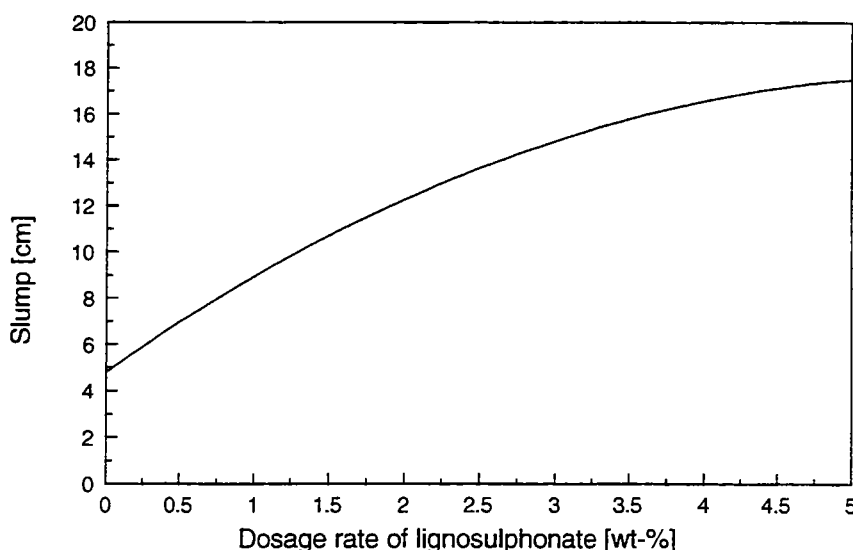
(2) Retardation

The lignosulphonates themselves interfere with the hydration of cement and cause some retardation. This effect is more pronounced when the calcium lignosulphonate admixture is used. High dosages of such admixtures can lead to unacceptable retardation.

The hydroxy-carbolic plasticizers (mostly sodium salts of citric, tatratic, gluconic, and maleic acid) are not very common, and hydroxylated polymers are rarely found in concrete construction practice.

Overdosing the concrete with an ordinary plasticizer increases workability. The increase in non-linear and the effect varies with the cement content and the initial workability (slump) of the mix. The following graphic shows the increase of slump as a function of the dosage of an ordinary Portland cement:

Figure 5:



Influence of the dosage rate of an ordinary lignosulphonate plasticizer on slump

Superplasticizers

Superplasticizers are based mainly on two types of polymers, namely the salts of formaldehyde naphthalene sulphonate and formaldehyde melamine sulphonate. The term superplasticizer indicates the much greater potential for increasing workability of concrete without undesirable side effects when compared to ordinary plasticizers.

The chemical composition of the superplasticizers differ from that of the ordinary plasticizers in that they do not delay the setting times and hardening of fresh concrete. On the contrary, some acceleration of the setting and hardening is usually observed. It is not entirely clear if the acceleration is due simply to a better dispersion of the cement particles or if other processes are also involved.

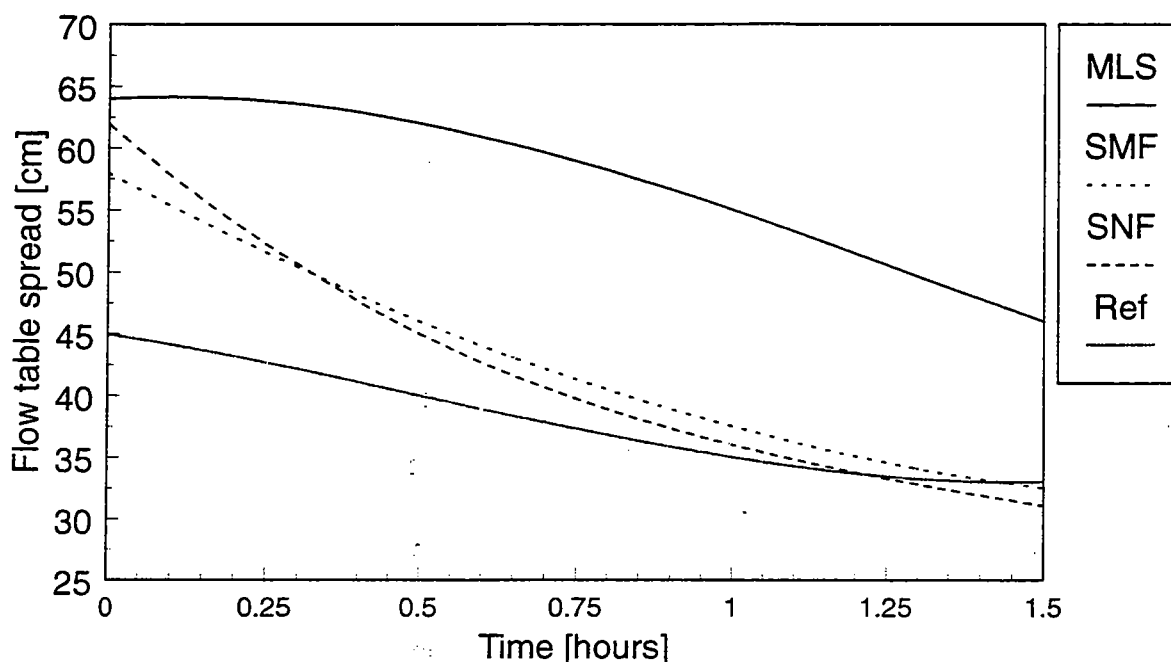
The accelerating effect of the superplasticizers appears to be primarily responsible for the relatively short periods of effectiveness of the admixture. Small additions of purified lignosulphonates are sometimes added to the admixture to moderate the rapid early loss of workability.

The periods of effectiveness of the superplasticizers have been quoted to vary between 15 minutes to 40 minutes. The period of effectiveness of the superplasticizer is usually measured as the time it takes for the workability of the mix to decrease to the level of the initial slump before the admixtures had been added.

It has been common practice in the ready-mixed concrete industry to delay the first dose of the superplasticizing admixture until the time the concrete reaches the delivery point. It is then possible to re-mix the concrete more than once, each time adding another dose of the superplasticizer and thus maintaining or even increasing workability without detrimental effect on the properties of hardened concrete.

The chemical nature of the superplasticizer determines its effectiveness in increasing the workability (slump, flow table spread, etc.). For e.g. to obtain a slump of about 25 cm from an initial value of 5 cm, it may be necessary to add 0.6% SMF or MLS-based superplasticizer whereas this could be accomplished with only 0.4% SNF-based admixture. In the following diagram the loss of workability is shown in a control concrete (containing no admixtures) compared with that containing MLS (**M**odified **L**igno **S**ulphonate), SMF (**S**ulphonated **M**elamine-**F**ormaldehyde) and SNF (**S**ulphonated **N**aphthalene-**F**ormaldehyde):

Figure 6:



Effect of MLS, SMF and SNF on loss of flow table spread

1.4.2 Air-entraining agents

The air-entraining admixtures are invariably organic substances which helps to generate microscopic bubbles of air in the fresh concrete. The majority of the commercially available ones are **based** on neutralised **wood resins** (vinsol) in which salts of abietic and pimeric acids are usual active chemical ingredients. A few air-entrained admixtures are based on the salts of fatty acids or other organic chemical compounds. It is also possible to use some types of the lignosulphonate based admixtures in higher dosages to produce simultaneous improvement of workability and generation of air-entrainment.

The technique of air-entrainment was originally developed in the USA primarily to increase the resistance of concrete to freezing and thawing and to the scaling effects produced by de-icing salts (mostly sodium or calcium chloride). The entrainment of air in concrete has been defined as the introduction into fresh concrete of air in controlled amounts and in the form of properly-sized bubbles (preferably within the size range 0.05 to 0.3 mm diameter).

The entrained air in concrete should be clearly distinguished from accidentally entrapped air. The two differ in magnitude, amount, and properties of the air bubbles:

♦ **Entrained air**

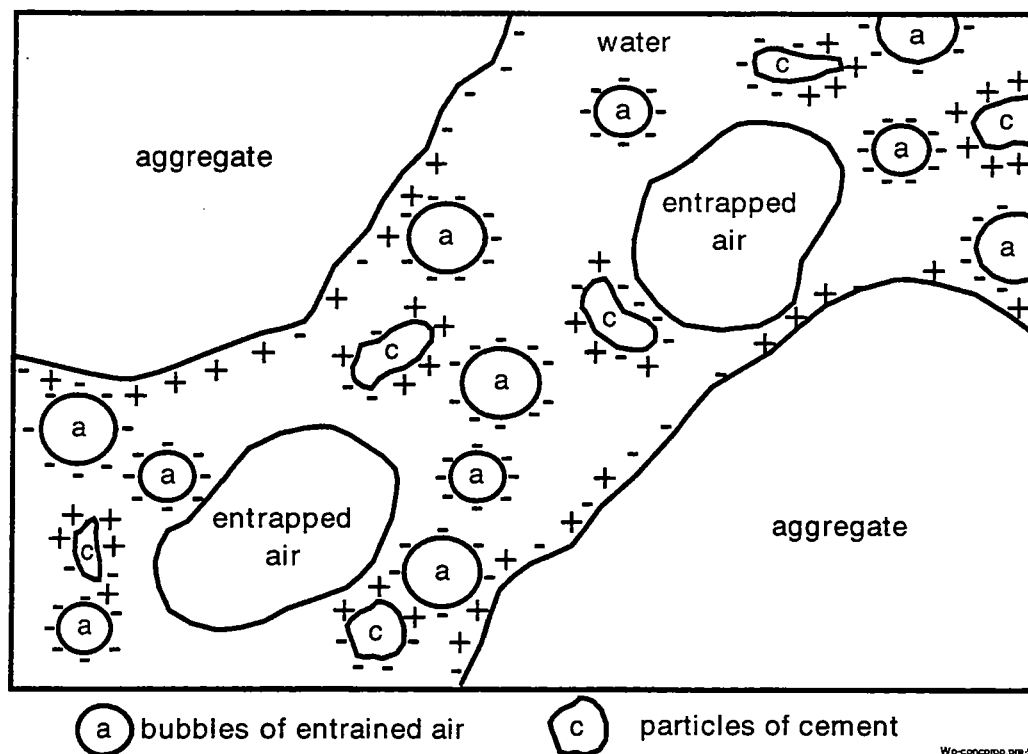
This air is intentionally incorporated by means of chemical admixtures, usually between 3 to 7% by volume and a maximum size of about 0.5 mm; entrained air produces discrete cavities in the cement paste so that no channels for the passage of water are formed and the permeability of the concrete is not increased. The voids never become filled with the products of hydration of cement as gel can form only in water.

♦ **Entrapped air**

Accidentally incorporated air is called entrapped air. This air usually forms very much larger bubbles, some as large as the familiar pockmarks on the surface of the concrete. The amount is in general between 0.5 to 1.5% by volume.

The air-entrained admixtures contain surfactants which are adsorbed on to the surfaces of the cement grains. As the microscopic bubbles form during mixing of the concrete, they stabilise in their small sizes and are attracted to the layers of surfactant on the cement particles. A simplified diagram of the cement-water-air structure is shown in the following:

Figure 7:



A simplified structure of the cement - water - aggregate - entrained air system in an air-entrained concrete mix

Air entraining agents should be added as solution, dissolved in the mixing of the concrete. If other admixtures are also used, the air entraining agent should be added separately rather

than mixed with the other admixtures, because sometimes there are reactions between materials that result in a decrease in the effectiveness of the air entraining agents.

The usual dosage rate of these materials is between 0.3 to 1.0 ml (density $\leq 1.1 \text{ g/cm}^3$) per kg of cement. This rate is roughly equivalent to 0.01%, solid admixtures substance to cement. The dosage rate can vary according to the composition of the mix.

Air entraining agents can be used with cements other than Portland. When used with blended cements, a larger amount of agent may be required to obtain the desired air content of the concrete.

1.4.3 Agents affecting setting and hardening

Accelerators

Accelerators have their primary application in cold weather concreting where they may be used to permit earlier starting of finishing operations. They reduce the time required for curing, and permit earlier removal of forms or loading of the concrete. Accelerators cannot be used as antifreeze agents since, at the allowable dosages, the freezing point will be lowered less than 2 °C.

Accelerating admixtures can be divided in three groups:

(1) **Soluble inorganic salts**

Most soluble inorganic salts will accelerate the setting and hardening of concrete to some degree; calcium salts generally being the most effective. **Calcium chloride** is the most popular choice because it gives more acceleration at a particular rate of addition than other accelerators and is also reasonably inexpensive. Admittedly it is very **corrosive** (as all water soluble chlorides) against the reinforcement of the concrete and therefore in many countries **forbidden** or limited at a particular level.

Soluble carbonates, aluminates, fluorides, and ferric salts have quick-setting properties. Sodium carbonate and sodium aluminate are the most common ingredients of shotcreting admixture formulations used to promote quick setting. Calcium fluoroaluminate can be used as admixtures to obtain rapid-hardening characteristics.

(2) **Soluble organic compounds**

A variety of organic compound have accelerating properties (although many more act as retarders), but triethanolamine, calcium formiate, and calcium acetate account for most commercial uses. They are commonly used in formulations of water-reducing admixtures to offset their retarding action.

Although triethanolamine is listed as an accelerator, recent research shows that its reaction with Portland cement is rather complex. It can cause retarding or flash setting, depending on the amount used.

(3) **Miscellaneous solid materials**

Solid materials are not often used for accelerating. Addition of calcium aluminate cements cause Portland cements to set rapidly, but strength development is poor. Concrete can be "seeded" by adding fully hydrated cement that has been finely ground during mixing to cause more rapid hydration. Finely divided carbonates (calcium or magnesium), silicate minerals, and silicas are reported to decrease setting time.

Retarders

Retarders can be used whenever it is desirable to set off the effects of high temperatures which decrease setting times. Prolonging the plasticity of fresh concrete can be used to advantage in placing mass concrete. Successive lifts can be blended together by vibration,

with the elimination of cold joints that would occur if the first lift were to harden before the next were placed.

Retarders can also be used to resist cracking due to form deflection that can occur when horizontal slabs are placed in sections. Concrete that has set but has acquired little strength is liable to microcrack when subsequent pouring alters the amount of form deflection. If the plastic period is prolonged, the concrete can adjust to form deflection without cracking.

The composition of retarders can be divided into several categories, **based on** their chemical composition:

Lignosulphonic acids and their salts (1)

Hydroxycarboxylic acids and their salts (2)

Sugar and their derivatives (3)

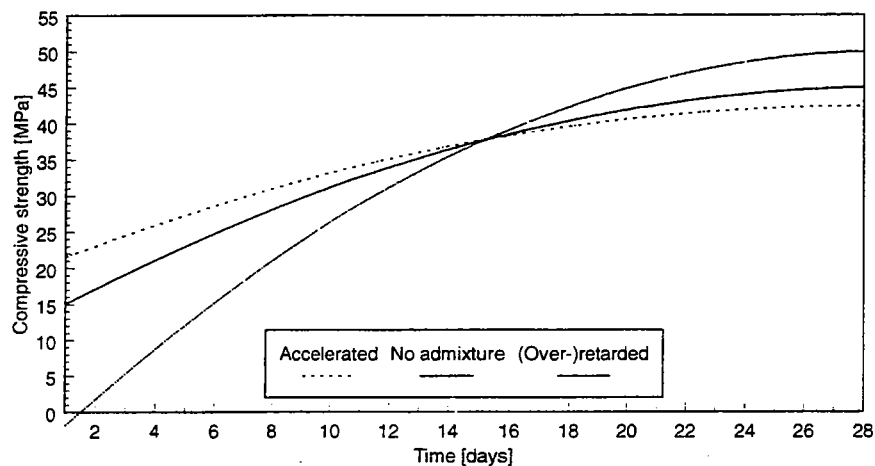
Inorganic salts (4)

It will be noted that categories (1) and (2) also possess water-reducing properties, and these admixtures can be classified under both groups. Lignosulphonate-based admixtures are prepared from pulp and paper industrial wastes, and studies have indicated that most of the retarding properties of these admixtures may be due to compounds that belong to category (2) or (3). Some inorganic salts (borates, phosphates, and zinc and lead salts) can act as retarders but are not used commercially.

The influence of an admixture on air entrainment should be considered, particularly if the admixture also has water-reducing properties. Retarders may also increase the rate of loss of workability in fresh concrete (slump loss), even when abnormal setting behaviour does not occur.

Whenever a retarding admixture is used, some reduction in the 1-day strength of the concrete should be anticipated. Within 7 days, the strength should approach that of an unretarded concrete unless an overdose has been used (see following diagram):

Figure 8:



Effect of retarders and accelerators on strength development of concrete

Retarding admixtures have been reported to increase ultimate compressive strength and, to a lesser extent, flexural strength. Although set-controlling admixtures are reported to increase drying shrinkage and creep, the effects depend on changes in mix design, time of hydration, and time of drying or loading.

1.4.4 Other admixtures

There are many other types of admixtures that are commercially available. The consumption of these various materials added together is less than the amount used of any single type so far mentioned. Some brief discussion of the more important kinds is warranted, however.

Bonding (or polymer) admixtures

Polymer latex emulsions are used to improve the bonding properties of concrete. This can be bonding between old and new concrete in repair work, or bonding between concrete and other materials, such as steel.

The brittle nature of concrete is an inherent property of the material and one that is overcome by the use of reinforcing materials. The very high porosity of concrete is also a disadvantage. Several approaches have been taken to improve concrete properties, resulting in quite different materials. Three different kinds of materials are often used:

PIC: Polymer-impregnated concrete

PIC involves filling the capillary pores of hardened concrete with a polymer

LMC: Latex-modified concrete

LMC is made by incorporating a polymer latex with fresh concrete, which improves the tensile properties of concrete.

Corrosion inhibitors

The incorporation of compounds that will prevent or reduce corrosion has been suggested for concretes in which corrosion of reinforcement can be a problem. Generally, these will be

salts that **contain an oxidizable ion**, such as nitrites, thiosulphates, benzoates, stannous salts, and ferrous salts.

It is however, doubtful whether the use of inhibitors is really warranted, since they are not considered to provide protection in the presence of chloride ion, which is precisely the situation in which protection is desired.

Dampproofing admixtures

The term 'dampproofing' implies prevention of water penetration into dry concrete or the transmission of water through concrete. No admixture can actually prevent such movement of water, although it may reduce the rate at which it occurs.

Certain formulations **based on salts of fatty acids** (soaps) or petroleum products (mineral oils and asphalt emulsion) may give the concrete a water-repellent effect. Such materials have been used to prevent the penetration of rain into porous concrete blocks but are not likely to affect the performance of dense, well-cured concrete.

Expansive Cements

One of the major disadvantages of Portland cement concrete is its high drying shrinkage and its susceptibility to tensile strength when volume contraction is wholly or partially restrained.

The development of expansive cements dates back about 60 years. Commercial production began in the US in the late 1960s, although total production remains quite small, about 500'000 tons annually. A standard specification, ASTM C845-90, covers expansive cements.

All three variants of present-day expansive cements (Type K, M, and S) are **based on** the formation of **ettringite** (hydrated calcium sulphoaluminate) in considerable quantities during the first few days of hydration. The material from which ettringite is formed differ substantially in each cement, but all require a source of calcium aluminate and sulphate ions. Expansion has also been achieved by using clinker with high content of free lime as admixture to cause expansion of a superplasticized concrete mix.

Successful use of expansive cements depends upon proper control of the expansion of the cement during hydration and is **sensitive to** a number of variables, for example:

Reinforcement -- Mix design -- Handling and curing

Grouting admixtures

Cement-based grout used for speciality applications such as **cementing oil well** contain different admixtures. Flocculating admixtures, thickeners, and mineral admixtures are used to prevent bleeding and segregation and to increase cohesion and retention of water during pumping. Retarders are commonly used to extend pumping times.

1.5 Mixing and curing water for concrete

1.5.1 Introduction

The quality of water is important because poor-quality water may affect the time of setting, strength development, or cause staining. Almost all natural water, fresh water, and water treated for municipal use are satisfactory as mixing water for concrete if they have no pronounced odour or taste.

Because of this, very little attention is usually given to the water used in concrete, a practice that is in contrast to the frequent checking of admixture, cement, and aggregate components of the concrete mixture.

1.5.2 Effect of impurities

A popular criterion as to the suitability of water for mixing concrete is the classical expression:

<p>If water is fit to drink it is all right for making concrete</p>
--

This does not appear to be the best basis for evaluation, since water containing small amounts of sugar or citrate flavouring would be suitable for drinking but not mixing concrete, and, conversely water suitable for making concrete may not necessarily be fit for drinking.

The most extensive series of tests on the subject "Impurities in mixing water" was conducted by Abrams (ACI Proceedings, Vol 20, 1924, 442-486). Approximately 6000 mortar and concrete specimens representing 68 different water samples were tested in this investigation. Among the water tested were sea and alkali water, bog water, mine and mineral water, and water containing sewage and solutions of salt. Tests with fresh and distilled water were included for comparative purposes. Some of the more significant conclusions based on these data are as follows:

The time of setting of Portland cement mixtures containing impure mixing water was about the same as those observed with clean fresh water with only few exceptions. In most instances, the water giving low relative compressive strength of concrete caused slow setting.

- ◆ Non of the waters caused unsoundness of the neat Portland cement paste when tested over boiling water.
- ◆ In spite of the wide variation in the origin and type of water used, most of the samples gave good results in concrete due to the fact that the quantities of injurious impurities present were quite small.
- ◆ The quality of mixing water is best measured by the ratio of the 28-day concrete or mortar strength to that of similar mixtures made with pure water. Water giving strength ratios that are below 85% should be considered unsatisfactory.
- ◆ Neither odour nor colour is an indication of quality of water for mixing concrete. Water that was most unpromising in appearance gave good results. Distilled waters gave concrete strength essentially the same as other fresh waters.
- ◆ Based on a minimum strength-ratio of 85% as compared to that observed with pure water, following samples were found to be unsuitable for mixing concrete:
 - acid water
 - lime soak water from tannery waste
 - carbonated mineral water discharged from galvanising plants
 - water containing over 3% sodium chloride or sulphate
 - water containing sugar or similar compounds

The concentration of total dissolved solids in these waters was over 6'000 ppm except for the highly carbonated water that contained 2'100 ppm total solids. Very few natural waters other than sea water, contain more than 5'000 ppm of dissolved solids.

- ◆ Based on the minimum strength-ratio of 85%, the following waters were found to be suitable for mixing concrete:
 - bog and marsh water
 - waters with a maximum concentration of 1% sulphate
 - sea water (but not for reinforced concrete)
 - alkali water with a maximum of 0.15% Na_2SO_4 or NaCl
 - water from coal and gypsum mines
 - waste water from slaughterhouses, breweries, gas plants, and paint and soap factories.

1.5.3 Effects of algae on air content and strength

A rather extensive series of laboratory tests showed that the use of water containing algae had the unusual effect of entraining considerable quantities of air in concrete mixtures with an accompanying decrease in strength. The data in the following table were based on tests with 19-mm maximum-size aggregate concrete having a w/c ratio of 0.5 and a slump of 4.0 to 7.5 cm, with a constant ratio of coarse to fine aggregate:

Table 13:

Algae in mixing water [%]	Air in concrete [%]	Compr. strength at 28 days [MPa]
none (control mix)	2.2	33.3
0.03	2.6	33.4
0.09	6.0	27.9
0.15	7.9	22.8
0.23	10.6	17.8

In addition to the detrimental effect of strength, one of the important aspects of these data is that considerable quantities of air can be entrained in concrete by the use of mixing water containing algae.

1.5.4 Curing water

There are two primary considerations with regard to the suitability of water for curing concrete:

- ♦ One is the possibility that it might contain impurities that would cause staining, and the other
- ♦ that it might contain aggressive impurities that would be capable of attacking or causing deterioration of concrete. The latter possibility is unlikely, especially if water satisfactory for use in mixing concrete is employed.

In some instances the staining or discoloration of the surface of concrete from curing water would not be objectionable.

The most common cause of staining is usually a relatively high concentration of iron or organic matter in the water; however, relatively low concentrations of these impurities may cause staining, especially if the concrete is subjected to prolonged wetting by run off of curing water from portions of the structure.

Test data show that there is no consistent relationship between dissolved iron content and degree of staining. In some cases, 0.08 ppm of iron resulted in only a slight discoloration and in other cases, waters with 0.06 ppm of iron gave a moderate rust-coloured stain, while 0.04 ppm produced considerable brownish-black stain.

2. LITERATURE FOR ADMIXTURES AND MIXING WATER

- ◆ P. Klinger, J. Lamond: Concrete and Concrete-Making Materials; ASTM, STP 169C, Aug. 1994
- ◆ P. Bartos: Fresh Concrete, Properties and Tests; Elsevier, Amsterdam, 1992
- ◆ K. Wesche: Baustoffe für tragende Bauteile, Teil 2: Beton, Mauerwerk; Bauverlag, Wiesbaden, 1992
- ◆ A. Neville: Properties of Concrete; Longman Scientific & Technical, New York, 1991
- ◆ B. Addis: Fulton's Concrete Technology: Portland Cement Institute, Midland, South Africa, 1986
- ◆ S. Mindess: Concrete; Prentice-Hall, Englewood Cliffs, New Jersey, 1981

3. APPENDICES**3.1 REFERENCES**

- [1] DIN 4226 (1983): Zuschlagstoff für Beton: Deutsches Institut für Normung e.v.; Beuth Verlag GmbH, Berlin
- [2] B. Addis et al.: Fulton's Concrete Technology, chapter 3, PCI, Midland, South Africa, 1986; (All extracts mainly from this paper)
- [3] R. Rhoades et al.: Petrographic and mineralogic characteristics of aggregates; ASTM symp. on Mineral Aggregates, Philadelphia, 1948, p. 20 - 48
- [4] British Standard 812 (1967): Mineral, Aggregates, Sand & Fillers, Brit. Stand. House, 2 Park Street, London, W1Y 4AA
- [5] J. Phemister et al.: Roadstone, geol. aspects and phys. tests; London, Dept. of Sc. and And. Res. Road Spec. Report No. 3, 1946
- [6] D. Davis, M. Alexander Properties of aggregate in concrete; Hippo Quarries Techn. Publ. (1992), 94 Rivonia Road, Sandton 2199, South Africa
- [7] M. Kaplan: The flexural and compressive strength of concrete as affected by the properties of coarse aggregates; Proc. American Concrete Institute v. 55, May 1959, p. 1193 ff
- [8] L. Roberts et al.: Dictionary of Geological Terms; American Geological institute, Anchor Books, New York (1983)
- [9] Webster's New World Dictionary of American English, Third College Edition, Cleveland, USA (1988)
- [10] L. Mercer et al.: The law of grading for concrete aggregates; Melbourne, Techn. Coll. Press, 1951, Research Bull. no. 1
- [11] V. Barnher Gap-graded concrete; London Cement & Concrete Association, 1952, C & CA Library Translation no. 42
- [12] H. Schäffer Beton mit Ausfallkörnungen; Betonwerk + Fertigteil-Technik, Heft 6/1979
- [13] A. D. Buck: Recycled concrete as source of aggregate; Proc. American Concrete Institute, v. 74, 1977, p. 212-219
- [14] F. Rossouw: Report on the suitability of some metallurgical slags as aggregate for concrete; Pretoria, NBRI, 1981, NBRI Special Report Bou 56, p. 1 - 25

3.2 Relevant ASTM Standards

3.2.1 Aggregate

C 33-90	Specification for Concrete Aggregates
C 40-84	Test for Organic Impurities in Sands for Concrete
C 70-79	Test for Surface Moisture in Fine Aggregate
C 88-90	Test for Soundness of Aggregates by Use of Sodium Sulphate or Magnesium Sulphate
C 123-90	Test for Lightweight Pieces in Aggregates
C 131-89	Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and impact the Los Angeles Machine
C 227-87	Test method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
C 289-87	Test method for Potential Reactivity of Aggregates (Chemical Method)
C 294-86	Descriptive Nomenclature of Constituents of Natural Mineral Aggregates
C 330-89	Specification for Lightweight Aggregates for Structural Concrete
C331-89	Specification for Lightweight Aggregates for Concrete Masonry Units
C 332-87	Specification for Lightweight Aggregates for Insulating Concrete
C 586-86	Test method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)
C 637-84	Specification for Aggregates for Radiation-Shielding Concrete
C 638-84	Descriptive Nomenclature of Constituents of Aggregates for Radiation Shielding Concrete
E 11-87	Specification for Wire Cloth Sieves for Testing Purposes

